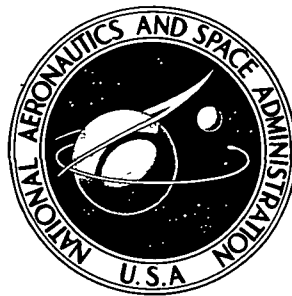


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AN INTERPRETATION OF PHOTOMETRIC
PARAMETERS OF BRIGHT DESERT REGIONS
OF MARS AND THEIR DEPENDENCE ON WAVELENGTH

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SUMMARY

The photometric function developed by Meador and Weaver (NASA TN D-7903) has been used with photometric data from the bright desert areas of Mars to determine the dependence of the three photometric parameters of the photometric function on wavelength and to provide qualitative predictions about the physical properties of the surface. Knowledge of the parameters permits the brightness of these areas of Mars to be determined for any scattering geometry in the wavelength range of 0.45 to 0.70 μm . Changes that occur in the photometric parameters due to changes in wavelength are shown to be consistent with their physical interpretations, and the predictions of surface properties are shown to be consistent with conditions expected to exist in these regions of Mars. The photometric function is shown to have potential as a diagnostic tool for the qualitative determination of surface properties, and the consistency of the behavior of the photometric parameters is considered to be support for the validity of the photometric function.

INTRODUCTION

The photometric function developed by Meador and Weaver (ref. 1) is an attempt to describe the effects of multiple scattering by particulate surfaces. The function contains both an improved treatment of particle shadowing and parameters that qualitatively relate to such physical properties of the scattering surface as particle size, surface compactness, and single-particle albedo. The function can be used to extrapolate limited brightness measurements to all scattering geometries and to provide qualitative information about the physical properties of the scattering surface from remote photometric data, a task that was previously impossible because of the strictly empirical nature of the existing photometric theories. The photometric function has been verified by numerous measurements on laboratory samples (ref. 1), but its dependence on wavelength has not been determined. That the photometric behavior of particulate surfaces can be a strong function of wavelength has been found by many

investigators (for example, refs. 2 and 3); therefore, before multispectral data can be properly analyzed, the dependence of the photometric parameters of reference 1 on wavelength must be determined. If the wavelength behavior of the photometric parameters agrees with predictions based on their physical interpretations, it will lend support to the validity of the photometric function and to the physical interpretation of the parameters. An atmospheric contribution to the total brightness is neglected in this analysis because indications are that the Mars atmosphere is transparent enough to ignore absorption and multiple scattering (ref. 4).

The purpose of this paper is, therefore, twofold: (1) to determine the dependence of the photometric parameters for the planet Mars on wavelength in order to facilitate the use of the photometric function in the analysis of the multispectral photometric data and (2) to determine whether the physical properties of the Mars surface (as predicted by the dependence of the parameters on wavelength) are consistent with qualitative predictions. If consistency is found, the validity of the photometric function and the physical interpretation of the parameters are further supported.

SYMBOLS

a_0	phase-function asymmetry factor (photometric parameter)
a_1	measure of amount of multiple scattering (photometric parameter)
a_2	packing factor (photometric parameter), $n\rho^3$
C	parameter in equation (15)
C_1, C_2	coefficients in equation (16)
C_3, C_4, C_5	coefficients in equation (17)
f	shadowing-correction factor
G	function defined by equation (10)
H	function defined by equation (9)
i	incident angle of impinging collimated radiation with respect to surface normal

J_1	function defined by equation (11)
J_2	function defined by equation (12)
k	Minnaert exponent
k_0, k_1, k_2, k_3	coefficients in equation (14)
n	particle number density
p	phase function
x	integration variable (see eq. (2))
α	phase angle (angle between direction of incidence and emission)
δ	angular deviation from mirror-point geometry (see eq. (7))
ϵ	emission angle of observed scattered radiation with respect to surface normal
λ	wavelength
μ	function defined by equation (3)
ν	function defined by equation (4)
ρ	effective particle radius
Φ	surface brightness normalized to unity at $i = \epsilon = 0$
ϕ	azimuthal angle between planes of incidence and emission

Subscript:

M Minnaert (see eq. (15))

THE PHOTOMETRIC FUNCTION

The Meador-Weaver photometric function is a semiempirical formulation that describes multiple scattering processes in the diffuse reflection of solar radiation. It includes an improved treatment of particle shadowing, which causes the planetary opposition effect, and it gives information about such physical properties of the surface as particle size, single-particle albedo, and compactness. The function is given by (ref. 1)

$$\Phi(i, \epsilon, \alpha) = \frac{\cos i}{(1 + a_0 + a_1)(\cos i + \cos \epsilon)} \left[(1 + a_0 \cos \alpha) f(i, \epsilon, \alpha, a_2) + a_1 (\cos i + \cos \epsilon) \right] \quad (1)$$

where Φ is the surface brightness (normalized to unity at $i = \epsilon = 0$); i is the angle of incidence of impinging collimated radiation with respect to the surface normal; ϵ is the angle of emission of observed scattered radiation with respect to the surface normal; α is the phase angle; and a_0 , a_1 , and a_2 are parameters that contain information about the surface and include the dependence of the function on wavelength. The factor f is the shadowing-correction factor and is given by

$$f(i, \epsilon, \alpha, a_2) = e^{\mu - \nu} + \nu \int_0^1 \exp \left\{ \mu - \frac{\nu}{6\pi} \left[3\pi x + 2(2 + x^2)(1 - x^2)^{1/2} + 6x \sin^{-1} x \right] \right\} dx \quad (2)$$

where

$$\mu = \frac{4a_2(1 + \cos \alpha)}{3 \sin \alpha} \quad (3)$$

$$\nu = \frac{\pi a_2 (\cos i + \cos \epsilon)}{\sin \alpha \cos i \cos \epsilon} \left[\sin^2 \alpha + 2(1 + \cos \alpha) \cos i \cos \epsilon \right]^{1/2} \quad (4)$$

$$\cos \alpha = \cos i \cos \epsilon + \sin i \sin \epsilon \cos \phi \quad (5)$$

and ϕ is the azimuthal angle between the planes of incidence and emission.

As noted in reference 1, equation (2) approaches an incorrect limit at either grazing incidence or emission. This behavior has been found to be the result of an inadequate theoretical treatment of the particles in the surface layer (unpublished results) and can be partially corrected by setting $f = 1$ when the calculated value of f is less than unity, which occurs for large values of either i or ϵ . The complete normalized photometric function is then the combination of equation (1) and either the

shadowing-correction factor of equation (2) or its correction ($f = 1$) when the f of equation (2) is less than unity.

ANALYSIS PROCEDURES

The semiempirical parameters a_0 , a_1 , and a_2 appear in a complex manner in equations (1) to (4) and are strongly coupled, both physically and mathematically. The procedure for their determination, developed in reference 1, basically involves an iterative matching followed by consistency checks. This procedure was influenced by the fact that a plot of $\log_e (\Phi \cos \epsilon)$ against $\log_e (\cos i \cos \epsilon)$ for coplanar geometries and fixed α (called a Minnaert plot) yields a straight line over a limited range of $\log_e (\cos i \cos \epsilon)$ near unity and thus facilitates curve fitting. In addition, much of the existing planetary photometric data is presented as Minnaert plots.

The linear portion of the Minnaert plot of equation (1) starts at and continues for some distance from the mirror-point geometry defined by $i = \epsilon$ in a coplanar geometry with i and ϵ on opposite sides of the surface normal. The slope k of this linear portion is obtained from

$$k(\alpha) = \lim_{\delta \rightarrow 0} \left\{ \frac{d[\log_e (\Phi \cos \epsilon)]}{d[\log_e (\cos i \cos \epsilon)]} \right\}_{\alpha=\text{Constant}} \quad (6)$$

where δ is the angular deviation from the mirror-point geometry and is given by the equation

$$\delta = 1 - \frac{\alpha}{2} = \frac{\alpha}{2} - \epsilon \quad (7)$$

Using the definition of equation (7), equation (6) yields

$$k(\alpha) \approx 1 - \frac{1}{2} \cos^2 \frac{\alpha}{2} - \frac{p(\alpha, a_0) H(\alpha, a_2) - a_1 \cos(\alpha/2)}{p(\alpha, a_0) G(\alpha, a_2) + 2a_1 \cos(\alpha/2)} \cos^2(\alpha/2) \quad (8)$$

where

$$H(\alpha, a_2) = \frac{4\pi a_2 \tan^2(\alpha/2)}{\sin \alpha} \left\{ J_1(\alpha, a_2) - \exp \left[\frac{4a_2(1 - 3\pi + \cos \alpha)}{3 \sin \alpha} \right] \right\} \quad (9)$$

$$G(\alpha, a_2) = \frac{4\pi a_2}{\sin \alpha} J_2(\alpha, a_2) + \exp\left[\frac{4a_2(1 - 3\pi + \cos \alpha)}{3 \sin \alpha}\right] \quad (10)$$

$$J_1(\alpha, a_2) = J_2(\alpha, a_2) - \frac{2a_2}{3 \sin \alpha} \int_0^1 \left[3\pi x + 6x \sin^{-1} x + 2(2 + x^2)(1 - x^2)^{1/2} \right] \\ \times \exp\left\{ \frac{2a_2}{3 \sin \alpha} \left[2 + 2 \cos \alpha - 3\pi x - 6x \sin^{-1} x - 2(2 + x^2)(1 - x^2)^{1/2} \right] \right\} dx \quad (11)$$

$$J_2(\alpha, a_2) = \int_0^1 \exp\left\{ \frac{2a_2}{3 \sin \alpha} \left[2 + 2 \cos \alpha - 3\pi x - 6x \sin^{-1} x - 2(2 + x^2)(1 - x^2)^{1/2} \right] \right\} dx \quad (12)$$

and $p(\alpha, a_0)$ is the linear anisotropic phase function defined as

$$p(\alpha, a_0) = 1 + a_0 \cos \alpha \quad (13)$$

Details of the development of equations (8) to (12) are in appendix B of reference 1.

The iterative procedure is as follows:

(1) For a given value of phase angle, a Minnaert plot of brightness data is constructed and the slope k of the linear portion of these data near the mirror-point geometry is determined. This is repeated for a range of phase angles that is sufficient to define the slope k as a function of phase angle.

(2) Choose a $k(\alpha_1)$ and a $k(\alpha_2)$ away from both the midpoint and the extremes of the range of phase angle, and use it with both equation (8) and an assumed value of a_0 in order to determine the value of a_2 that forces $a_1(\alpha_1) = a_1(\alpha_2)$. This is repeated for enough assumed values of a_0 between its maximum value of +1 and its minimum value of -1 to define a_1 and a_2 as functions of a_0 .

It might seem that the sets of a_0 , a_1 , and a_2 that are determined in this way could be used to compare equation (8) with the $k(\alpha)$ data of step (1) to determine which set forces a match. This comparison, however, is found to be too insensitive to determine the three parameters without considerable ambiguity. It is necessary, therefore, to use something other than k for comparison purposes. A comparison, however, that is sensitive enough to determine the three parameters is that comparison between equation (1) and the brightness data of step (1). The procedure continues as follows:

(3) The sets of parameters determined in step (2) are used with equation (1) and are compared with the brightness data used in step (1) for a particular geometry, in this case, $\epsilon = 0$ (normal emission). (Since the brightness data and eq. (1) are not referenced to a single calibration standard, it is necessary to normalize the brightness data at some midrange value of phase angle to match the values from eq. (1).) The comparison is repeated until equation (1) matches the brightness data. The set of photometric parameters used with equation (1) to obtain the match is, thus, the set unique to that data.

This procedure was successfully used in reference 1 to evaluate the photometric parameters for four basaltic materials where it was shown that steps (1) to (3) do not bias the results toward the two particular geometries that were used to obtain the parameters because the parameters adequately predicted the brightness of the materials for a third, quite different geometry: i fixed, while ϵ was varied over its entire range.

THE DATA

Two sets of Earth-based photometric measurements of the bright desert regions of Mars were used to evaluate the photometric parameters of equation (1). One set was the compilation of brightness data as a function of wavelength that was found in the 1974 Mars Engineering Model. Those data were a combination of Martian data measured at small phase angles (less than 60°) with photometric measurements (for angles larger than 60°) of Earth desert soils believed to be optically similar to the Martian surface. (See page 27, ref. 5.) Only the small angle data were used in the present analysis. The other set, contained in reference 2, was the variation of the Minnaert exponent k with phase angle and wavelength. None of the Mariner data were used because of the restriction of the far-encounter measurements to a single phase angle and, in the case of Mariner 9, the restriction of the data to a single, narrow band of wavelengths.

Since these two data sets are presented as Minnaert plots, the techniques of the preceding section are directly applicable. For the first part of the iterative procedure, results of reference 2 are considered more reliable than those of the 1974 Mars Engineering Model because the values of k in reference 2 were obtained directly from the slopes of Minnaert plots, whereas the data used by the 1974 Mars Engineering Model admittedly contain a number of arbitrary and unjustified assumptions about the behavior of k . However, the results of reference 2 are not completely reliable because of large experimental scatter, uncertainties in the measurements, and insufficient data to definitely establish the exact dependence of k on phase angle and wavelength. It was also necessary to correct figure 3 of reference 2 because the data for the phase angles 17.7°

and 18.5° were plotted incorrectly. The brightness data of the 1974 Mars Engineering Model are considered reliable for the latter part of the iterative procedure because they are based on direct observations.

DETERMINATION OF PHOTOMETRIC PARAMETERS

The variation of k with the phase angle was determined from reference 2 by the construction of a function that fitted both the raw data for a wavelength of $0.605 \mu\text{m}$ and the refined data for the phase angles 10.3° and 17.7° . The function is

$$k(\alpha, \lambda) = k_0 + \frac{k_1}{\lambda} + \left(k_2 + \frac{k_3}{\lambda}\right)\alpha \quad (14)$$

where λ is the wavelength in μm , α is the phase angle in radians, $k_0 = 5.158 \times 10^{-1}$, $k_1 = -7.960 \times 10^{-3}$, $k_2 = 1.674$, and $k_3 = -5.342 \times 10^{-1}$. Figure 1 shows the variation of k with phase angle for $\lambda = 0.605 \mu\text{m}$; the linear regression curve fit was used to correlate the data. (Note that the two data points for the larger values of phase angle were plotted incorrectly in the original reference. The corrected values used here are from ref. 6.) Equation (14) was used in step (2) of the iterative procedure to determine the values of a_1 and a_2 for the range of a_0 .

The brightness data of the 1974 Mars Engineering Model are given in the form of a Minnaert function defined as

$$\Phi_M(i, \epsilon, \alpha, \lambda) = C(\alpha, \lambda)(\cos i)^{k(\alpha, \lambda)}(\cos \epsilon)^{k(\alpha, \lambda)-1} \quad (15)$$

where

$$k(\alpha, \lambda) = 0.475 + 0.375\lambda + C_1\alpha + C_2\alpha^2 \quad (16)$$

and

$$C(\alpha, \lambda) = 0.621 + 0.238\lambda + (C_3 + C_4\lambda)(C_5\alpha + \alpha^2) \quad (17)$$

with $C_1 = 0.0117576$, $C_2 = -7.1311 \times 10^{-5}$, $C_3 = 1.4528 \times 10^{-4}$, $C_4 = -1.5227 \times 10^{-4}$, $C_5 = -96.4273$, and α given in degrees.

Equation (15) was used in step (3) of the iterative procedure to determine a_0 , a_1 , and a_2 from comparisons with equation (1). Figure 2 shows the overall ability of equation (1) to match the brightness data of the 1974 Mars Engineering Model for $\lambda = 0.55 \mu\text{m}$.

In evaluating figure 2, it should be recalled that a different data set (namely, that of ref. 2) was used in the first two steps of the iterative procedure and resulted in a grouping of the photometric parameters that directly affected the ability of equation (1) to fit the data of the 1974 Mars Engineering Model. In determining the criteria for a visual match in the comparisons, of which figure 2 is an example, the brightness data at phase angles greater than about 60° were given less weight because of the inaccuracies that might exist with the failure of equation (2) to approach a proper limit at grazing incidence and because of the inapplicability of the data of the 1974 Mars Engineering Model for phase angles greater than 60° .

The numerical values of the three photometric parameters are given in table I for the range of $\lambda = 0.45$ to $0.70 \mu\text{m}$. Figures 3, 4, and 5 show graphically the variation of a_0 , a_1 , and a_2 , respectively, with wavelength and use third-order polynomials to correlate the data. The coefficients of the polynomials are given in table II to facilitate numerical generation of the data.

PHYSICAL INTERPRETATION OF PARAMETERS

The photometric function used herein was developed not only to provide a more accurate extrapolation of limited brightness data to arbitrary geometries but also to provide information about the physical properties of the surface material from data analysis. The photometric parameters indeed do have physical meaning, as will be evident from the following discussion; however, it is also evident from the discussion that further theoretical and experimental evaluation of the precise meaning of the parameters is needed. At present, therefore, the parameters can only be considered to give qualitative predictions about the physical properties of the surface. It should be emphasized that the physical properties determined from photometry apply only to the layer of surface material that contributes to the scattering process, in the case of visible radiation, probably a depth of only a few particle diameters.

The determination of a_0 from experimental data should yield information on mean particle size through the relation of particle size to the particle transmittance (provided large particles of the same material are essentially opaque). This condition should be applicable to much of the sandy desert material of Mars since it is thought to be mostly feldspar, mafic minerals, and basalt fragments, but not quartz (ref. 7). The parameter a_0 is limited to values between -1 and 1 where an excess of forward scattering (as could occur by means of transmission through small particles) is indicated by negative values, isotropic scattering is indicated by a value of zero, and an excess of backscattering is indicated by positive values. The parameter a_1 is a measure of the multiple scattering that occurs in the particulate material and, thus, relates to the single-particle albedo.

The limits of a_1 are zero and infinity and correspond to the limit of very dark, single-scattering materials and to the limit of very bright, Lambert surfaces, respectively. The parameter a_2 is the packing factor and is given in its simplest geometrical form by the equation

$$a_2 = n\rho^3 \quad (18)$$

where n is the particle number density and ρ is the effective particle radius. The packing factor can have values between zero and unity where the smaller the value, the more porous is the structure.

RESULTS

Because of the complex interrelationships of the photometric parameters with each other and with particle size and wavelength, the delineation of the results and how they support the validity of the photometric function is as follows: first, the results are stated; second, there is a discussion of the variation of the parameters with particle size; and, last, there is a discussion of the variation of the parameters with wavelength. When analyzed by the techniques of the preceding sections, photometric data of the bright desert areas of Mars yield photometric parameters that correspond to a surface that has a mean particle size about the same as or smaller than $125 \mu\text{m}$, allows forward scattering to dominate, reflects light with low orders of multiple scattering, and has a tightly packed structure with low porosity.

The interpretation of the values of the photometric parameters is made more meaningful when the values are compared with those measured for other materials in the laboratory. Table III gives the results of measurements from reference 1 on two size ranges of each of two basaltic materials. (See ref. 8 for more specific information about the photometric apparatus and the test materials.) Note that for each material, as the size of the laboratory material increases, the value of a_0 increases. This behavior is consistent with the concept of a_0 as a measure of particle size through its relation to increased transmittance and, to some extent, diffraction by particles as size decreases. The parameter a_1 , since it is a measure of the amount of multiple scattering, should increase as the particle size decreases. This behavior is found in table III and occurs because some of the radiation that would be absorbed if the particles were large is transmitted through the smaller ones to be scattered again and partially to emerge as reflected light. This behavior explains the observation that, for sufficiently small particles, surfaces generally become brighter as particle size is diminished. The

packing factor a_2 is seen from table III to increase with a decrease in particle size; this implies a less porous structure for the small particle surfaces and a correspondingly smaller opposition effect. The fact that the values of a_2 in table III can exceed the geometrical limit of 0.125 that was obtained from equation (18) is explained in reference 1 in terms of the diffraction of the light that is passing through the apertures between particles; the diffraction increases as the particle size (and simultaneously, the aperture size) decreases. Accordingly, the packing factor obtained from the photometric data should be regarded as an apparent packing factor rather than as the geometrical definition of equation (18) that was used in the development of the photometric function. The difference between apparent and actual packing should increase with wavelength; thus a spectral dependence of a_2 that is impossible within its strictly geometrical interpretation is predicted.

The dependence of the photometric parameters for Mars on wavelength, as derived by the methods of this paper, is given in table I and in figures 3 to 5. The values of a_0 are large and negative, ranging from -0.34 at $\lambda = 0.45 \mu\text{m}$ to -0.71 at $\lambda = 0.70 \mu\text{m}$ (see fig. 3), and indicate that the particles are sufficiently small for forward scattering to predominate. If the material on the Mars surface has values of permittivity, permeability, and electrical conductivity that are not too different from those of the laboratory materials of table III, then the large negative values of a_0 imply a mean particle size about the same as or smaller than $125 \mu\text{m}$. The fact that reference 6 finds a mean particle size considerably larger than this may result from reference 6 using data integrated over the entire planet, excluding the poles, whereas the data used herein apply only to the bright desert areas where eolian forces could effect a considerably smaller mean particle size than might be expected in the nondesert area of Mars. The variation of a_0 with wavelength is in accord with an expected qualitative increase in material transmission at longer wavelengths; this further supports the validity of the photometric function and the physical interpretation of a_0 .

The small values of a_1 in table I indicate that the radiation reflected from Mars has undergone little multiple scattering. If it is assumed that penetration of the particulate surface by the radiation is necessary to produce multiple scattering and if, as the values of a_0 suggest, the mean particle size is small, there may be a substantial number of very small particles in the surface layer that fill the spaces between the larger particles and result in insufficient penetration of the surface material to permit significant multiple scattering to occur. The increase in the value of a_1 with wavelength, as shown in table I and figure 4, is consistent with the variation of a_0 since the increased transmission (as wavelength increases) that is implied by a_0 would lead to increased multiple scattering.

Since the values of a_2 in table I are much larger than those for the laboratory materials of table III and since the value of a_2 for each laboratory material increases with decreasing particle size, the implication is that the mean particle size of the Mars surface material is smaller than the laboratory materials; thus the conclusions drawn from the behavior of a_0 and a_1 are supported. The large values of a_2 in table I also indicate that the surface of Mars is more tightly packed than were the laboratory surfaces of reference 1 which were formed by dropping the particulate material from a height of about 0.5 m. The increase in a_2 with wavelength shown in table I and figure 5 is good support for the aforementioned speculation that diffraction of the light passing through the apertures between particles is an important contribution and that the calculated a_2 is an apparent, rather than a geometrical, packing factor.

CONCLUDING REMARKS

The photometric function developed by Meador and Weaver (NASA TN D-7903) has been used with photometric data from the bright desert areas of Mars to determine the dependence of the three photometric parameters of the photometric function on wavelength and to provide qualitative predictions about the physical properties of the Mars surface. Knowledge of the parameters permits the brightness of these areas of Mars to be determined for any scattering geometry over the wavelength range of 0.45 to 0.70 μm . The changes in the photometric parameters with wavelength are shown to be consistent with their physical interpretations, and the qualitative predictions of surface properties derived from the parameters are shown to be consistent with conditions expected to exist in those regions of Mars. The prediction of surface properties, however, is not yet quantitative, and in some instances the implications of the results are not well understood. Clearly, more theoretical and experimental work needs to be done before predictions of the physical properties of a surface from the photometric parameters can be considered quantitative.

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TABLE I.- DEPENDENCE OF PHOTOMETRIC PARAMETERS
OF MARS ON WAVELENGTH

λ , μm	a_0 (a)	a_1	a_2
0.45	-0.34	3.47×10^{-3}	0.651
50	- .48	6.14×10^{-3}	.826
.55	- .56	8.02×10^{-3}	.969
60	-.62	9.25×10^{-3}	1.091
65	-.68	9.59×10^{-3}	1.195
.70	- .71	1.02×10^{-2}	1.285

^aAccurate to approximately ± 0.01

TABLE II.- COEFFICIENTS FOR THIRD-ORDER POLYNOMIAL FIT
OF PHOTOMETRIC PARAMETERS FOR MARS

Parameter	λ^0	λ^1	λ^2	λ^3
a_0	4.5590	-21.8419	31.3330	-15.5554
a_1	-.1069	.4917	-.6996	.3372
a_2	-3.1139	14.4189	-16.7347	7.3051

TABLE III.- PHOTOMETRIC PARAMETERS FOR LABORATORY MATERIALS

[From reference 1]

Material	Mean particle diameter, μm	a_0	a_1	a_2
Colorado basalt (latite)	105	-0.40	0.28	0.32
Colorado basalt (latite)	225	-.10	.26	.15
Basalt dune sand	125	-.10	.25	.17
Basalt dune sand	210	.05	.20	.09

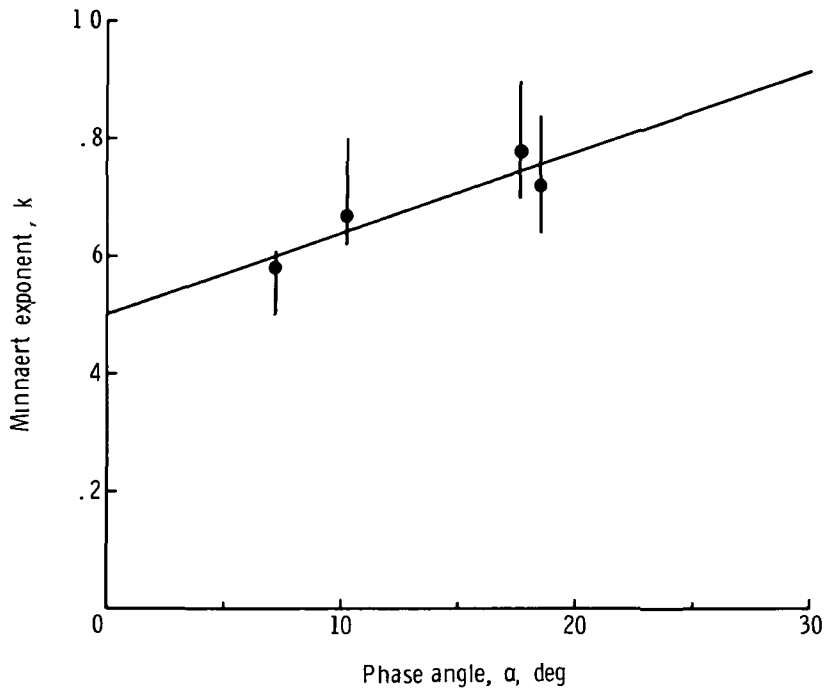


Figure 1.- Minnaert exponent for bright desert areas of Mars at wavelength of $0.605 \mu\text{m}$ (from ref. 2). Solid line is linear regression curve fit used to correlate data.

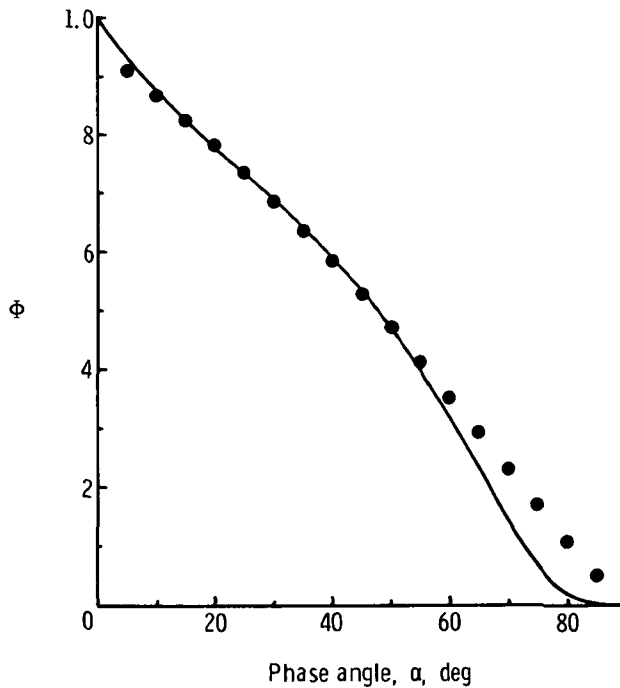


Figure 2.- Normalized brightness for bright desert areas of Mars at wavelength of $0.55 \mu\text{m}$ (from the 1974 Mars Engineering Model). Solid line is equation (1).

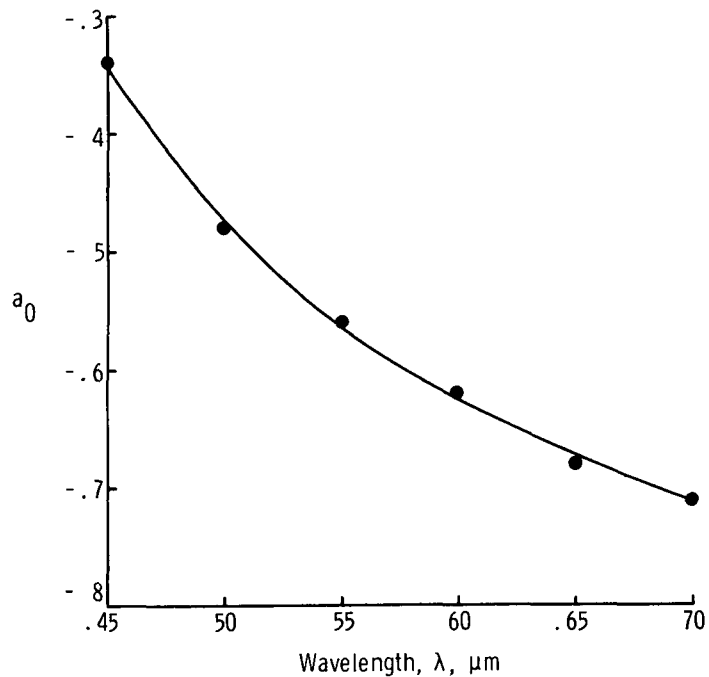


Figure 3.- Photometric parameter a_0 of equation (1).
Solid line is third-order polynomial fit to data.
(See table II for coefficients.)

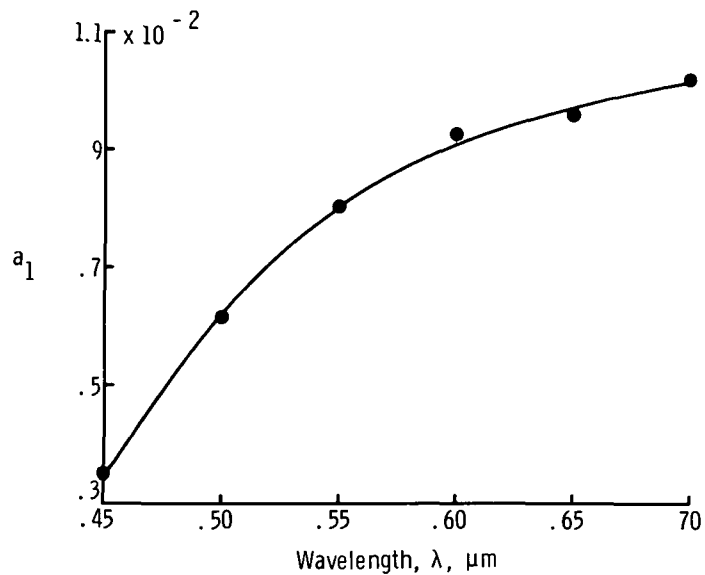


Figure 4.- Photometric parameter a_1 of equation (1).
Solid line is third-order polynomial fit to data.
(See table II for coefficients.)

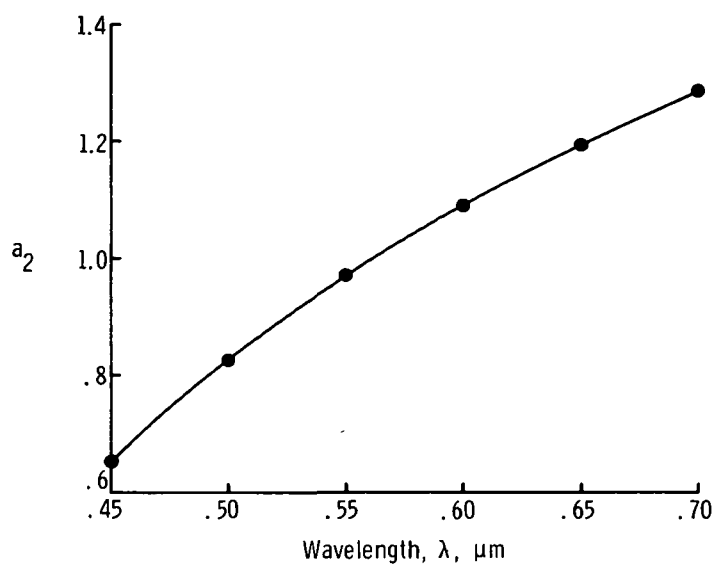


Figure 5.- Photometric parameter a_2 of equation (1).
Solid line is third-order polynomial fit to data.
(See table II for coefficients.)



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